FIELD AGING EFFECTS
OF
ASPHALT RUBBER MIXES AND CONVENTIONAL MIXES
FOR
RUNWAY SURFACE APPLICATIONS

By:

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INTRODUCTION

A number of studies have shown that the use of crumb rubber modifiers (CRM) with the asphalt binder, as part of the wet-process application in paving materials, seems to enhance their field performance. The improved performance of asphalt-rubber pavements compared with conventional asphalt concrete pavements has been attributed to improved rheological properties of the asphalt-rubber binder [1], and improved resistance to aging [2]. The influence of aging on the behavior of asphalt rubber mixes is critical to the development of more realistic mechanistic design procedures.

McGennis [3] and Liang and Lee [4] have reported an increase in the viscosity of asphalt rubber as a result of laboratory oven aging. Bahia and Davies [1] studied the effect of aging on asphalt binders before and after treatment with different types of crumb rubber modifiers. Binder specimens were aged using thin film oven (TFO) and pressure aging vessel (PAV). Binder resistance to fatigue was determined from the dissipated energy per load cycle (G") as obtained from the dynamic shear rheometer test. Results showed that all asphalt rubbers at all test temperatures exhibited less G" upon aging in TFO and PAV than the original binder, thereby indicating increased resistance to fatigue. Improvement in fatigue resistance of the asphalt rubbers compared to the original binders was more prominent at higher temperature. Harvey and Tsai [5] conducted a laboratory study to investigate the influence of long-term oven aging on the fatigue of asphalt concrete beam specimens using controlled-strain loading. Their results showed that aging is sensitive to the type of asphalt used and that stiffness increase associated with aging does not necessarily reduce the beam fatigue life. The application of the beam fatigue and stiffness results in the analysis of thin and thick pavement sections indicated that aging prolonged the fatigue life of the pavement structure. Saboundjian and Raad [6] evaluated the thermal cracking behavior of Alaskan field aged CRM mixes in comparison with conventional mixes. Thermal stress restrained specimen test results showed an improved thermal cracking resistance for the CRM mixes, especially when the wet process was used.

LABORATORY STUDY

In this study, the influence of field aging on two mixes was investigated: 1) Conventional asphalt concrete dense-graded (CAC-DG) and 2) Asphalt-rubber hot-mix gap-graded (ARHM-GG). These mixes were obtained from a 10-year old pavement test section that was constructed in southern California. After construction, field specimens were tested to determine the fatigue, rutting and thermal cracking characteristics of CAC-DG and ARHM-GG. Results of these tests were published elsewhere [7,8,9]. In this study, laboratory fatigue tests were conducted on beam specimens to determine stiffness and fatigue life, using controlled-strain fatigue beam tests performed at 22°C and -2°C. In addition, low-temperature cracking behavior was evaluated using thermal stress restrained specimen tests (TSRST) to determine the fracture temperature and fracture strength of these mixes. The Georgia Loaded Wheel Test (GLWT) was also performed to assess the resistance of these mixes to rutting under repeated load applications.

MATERIALS USED

Field slabs 12 in. wide, 20 in. long, and 4 in. thick were cut from the pavement section. These slabs were then cut in the laboratory into: beam specimens 2"x 2"x 16" for fatigue testing; beam specimens 2"x 2"x 10" for TSRST testing, and slab specimens 3"x 5"x 12" for GLWT testing. Properties of CAC-DG and ARHM-GG mixes are summarized in Tables 1 and 2.

Table 1.
CAC-DG Mix Properties.

Aggregate gradation		
Sieve (mm)	% passing	Specf.
3/4" (19)	100	100
1/2" (12.7)	97	95-100
3/8" (9.5)	89	80-95
#4 (4.75)	65	59-66
#8 (2.4)	48	43-49
#30 (0.6)	29	22-27
#200 (0.075)	8	0-11

The CAC-DG mix, placed in 1990, is according to Caltrans Standard Specifications, 1998 Edition, Section 39-2.02

Binder : AR-4000
Binder content : 5.7 % by weight of total mix
Voids : 1.6 %
Density : 24.1 KN/m^{3} (153 pcf)

Table 2.
ARHM-GG Mix Properties.

Aggregate gradation			Rubber gradation	
Sieve (mm)	% Passing	Specf.	Sieve (mm)	% Passing
3/4" (19)	100	100	#8 (2.4)	100
1/2" (12.7)	95	90-100	#10 (2)	95-100
3/8" (9.5)	81	78-92	#16 (1.2)	40-80
#4 (4.75)	35	28-42	#30 (0.6)	5-30
#8 (2.4)	24	15-25	#50 (0.3)	0-15
#30 (0.6)	15	5-15	#200 (0.075)	0-3
#200 (0.075)	5	2-7		

*The ARHM-GG mix, placed in 1990, is according to the Proposed
Standard Specifications for Public Works Construction, Section 203-11.3*

*Binder : Asphalt-Rubber consisting of :
AR-4000 asphalt cement
4% asphalt modifier (by weight of asphalt-rubber)
80% asphalt-cement and modifier
20% rubber
Binder content : 7.3 % by weight of total mix
Voids : 1.6 %
Density : 23.4 KN/m³ (148 pcf)*

FATIGUE EVALUATION

Controlled-strain flexure beam testing was used in the fatigue part of this study. All tests were conducted using MTS closed loop hydraulic testing equipment and a haversine displacement pulse having a width of 0.10 sec and a frequency equal to 60 cycles per minute. Fatigue tests were performed at 22°C and –2°C in an environmental chamber where the temperature of the specimens was maintained within ±1°C of the set temperature. The variation of applied load, and tensile and compressive strains across the center of the beam specimen was monitored with number of load applications. Fatigue failure was assumed to occur when the flexure stiffness determined from central beam deflections reduced by 50 percent.

The fatigue behavior of both CAC-DG and ARHM-GG is illustrated in Figures 1 and 2, where tensile strain is used as the limiting criteria.
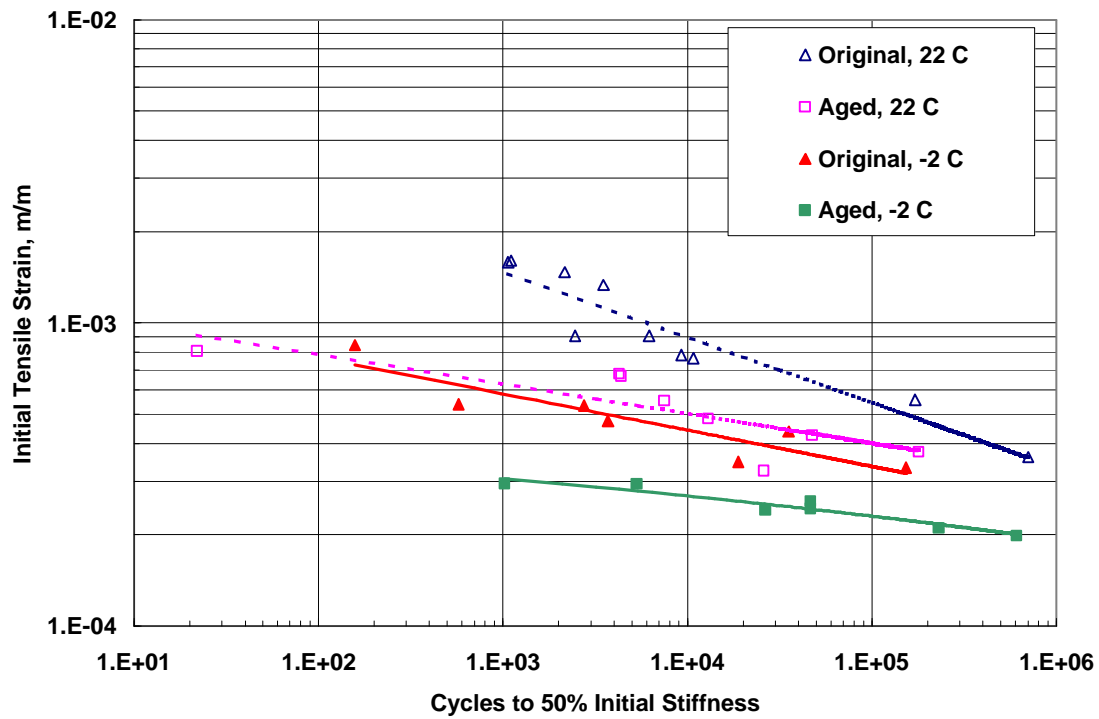
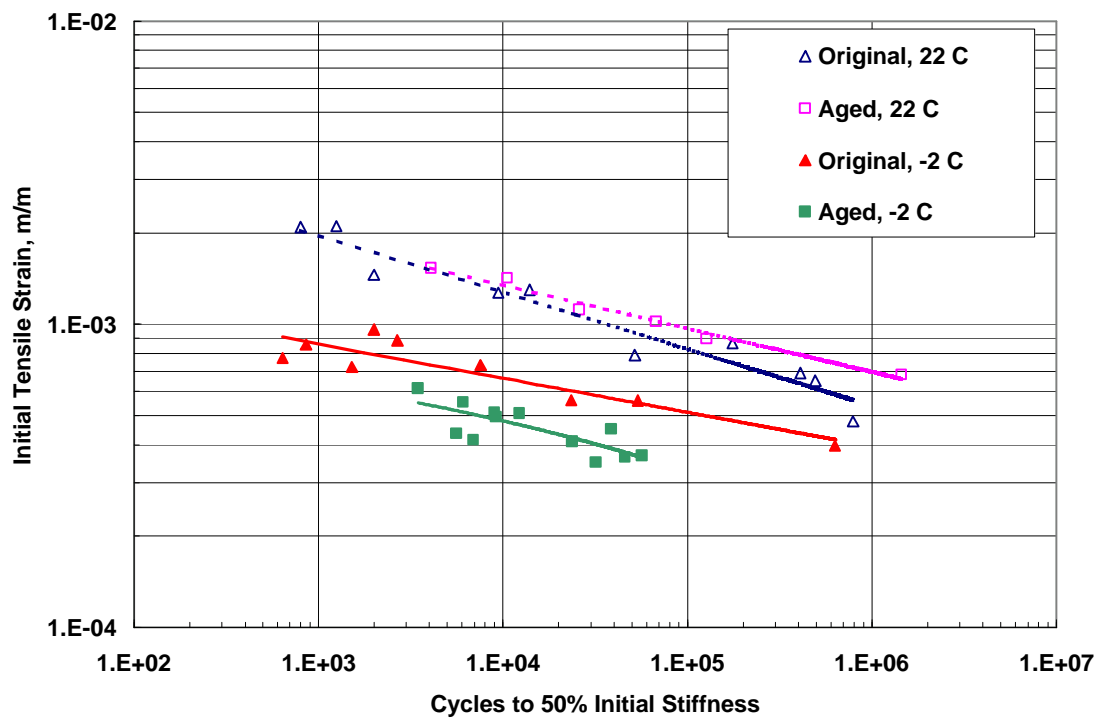Figure 1. CAC-DG Fatigue Relationships using Tensile Strain Criteria.

Figure 2. ARHM-GG Fatigue Relationships using Tensile Strain Criteria.

Test results for CAC-DG (Figure 1) clearly illustrate that aging reduces beam fatigue life for the testing conditions used in this study. The reduction is essentially more significant for tests run at -2°C than at 22°C. In case of ARHM-GG (Figure 2), aging has negligible effect on fatigue life for testing at 22°C. At -2°C, the reduction in fatigue life for ARHM-GG becomes more evident, but remains less significant than CAC-DG.

Although tensile strain on the underside of a pavement surface layer is considered in general as the critical response parameter for fatigue behavior, the use of distortion energy seems to be more appropriate for conditions of small tensile strain values or when the strain is compressive [8]. Compressive strains could occur on the underside of overlay layers depending on the relative stiffness of the pavement components.

According to Timoshenko and Goodier [10], the strain energy per unit volume for a linear elastic isotropic material is sometimes used as a limiting criterion to determine the stress state at failure. However, since in many isotropic materials, volumetric component of this energy does not contribute to failure, only the distortion energy component is considered. For a given state of normal stress (σ_x, σ_y, σ_z) and shear stress (τ_{xy}, τ_{yz}, τ_{zx}) at a given point relative to a Cartesian system of co-ordinates x-y-z in a linear elastic isotropic material, the distortion energy per unit volume, DE, is given by,

$$DE = [(1 + \upsilon)/6E][(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2] + (1/2G)(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2) \quad (1)$$

where E, G, and υ are the modulus of elasticity, the shear modulus, and Poisson's ratio, respectively.

In a beam fatigue test, the critical tensile stress, σ, alone is different than zero (i.e. uniaxial stress condition), and Equation 1 can be written as,

$$DE = (1+ \upsilon)\sigma^2/3E \qquad\qquad (2)$$

In this case, the initial DE is determined from initial bending stress σ and initial flexural stiffness, E. A Poisson's ratio of 0.35 was used for all beams tested in this study.

The fatigue test data were regressed to establish limiting criteria between load repetitions to failure, N_f, and the critical response parameters, in this case, tensile strain ε and initial distortion energy DE.

The following relationships were determined for both CAC-DG and ARHM-GG:

$$N_f = a (1/\varepsilon)^b \qquad\qquad (3)$$

$$N_f = a (1/DE)^b \qquad\qquad (4)$$

Regression coefficients a and b were independently determined for each relationship and are summarized in Tables 3 and 4.

Table 3.
Fatigue Regression Coefficients for Mixes at 22°C.

		a	b	R^2
$N_f = a \, (1 / e)^b$	Original CAC-DG	2.252E-09	4.147	0.893
	Original ARHM-GG	3.085E-11	5.022	0.941
	Aged CAC-DG	7.931E-10	4.022	0.683
	Aged ARHM-GG	2.342E-16	6.842	0.979
$N_f = a \, (1 / DE)^b$	Original CAC-DG	9757	2.574	0.948
	Original ARHM-GG	24762	2.891	0.946
	Aged CAC-DG	1216	3.647	0.852
	Aged ARHM-GG	31446	2.351	0.912
Note : N_f = Repetitions to 50% Initial Stiffness (Fatigue Life)				
e = Initial tensile Strain, m/m				
DE = Initial Distortion Energy, KPa				

Table 4.
Fatigue Regression Coefficients for Mixes at -2°C.

		a	b	R^2
$N_f = a \, (1 / e)^b$	Original CAC-DG	3.158E-20	6.993	0.838
	Original ARHM-GG	4.320E-20	7.342	0.828
	Aged CAC-DG	8.517E-45	13.464	0.904
	Aged ARHM-GG	1.797E-10	4.152	0.607
$N_f = a \, (1 / DE)^b$	Original CAC-DG	6313	5.170	0.848
	Original ARHM-GG	37739	3.603	0.888
	Aged CAC-DG	574	6.008	0.493
	Aged ARHM-GG	18005	1.993	0.692
Note : N_f = Repetitions to 50% Initial Stiffness (Fatigue Life)				
e = Initial tensile Strain, m/m				
DE = Initial Distortion Energy, KPa				

THERMAL CRACKING EVALUATION

The thermal stress restrained specimen test (TSRST) was used to determine the fracture temperature and the corresponding fracture strength of CAC-DG and ARHM-GG mixes. In this test, a prismatic specimen (2"x 2"x 10") is subjected to a controlled temperature drop (about 10°C/hr) until fracture occurs. The specimen length is kept constant throughout the test causing an induced tensile stress as the specimen attempts to contract due to the decreasing temperature [11].

For this study, six or seven specimens per aged mix were tested using the TSRST. The cooling rates averaged 9°C/hr. Figures 3 and 4 show stem plots of fracture temperatures and fracture strengths, respectively.
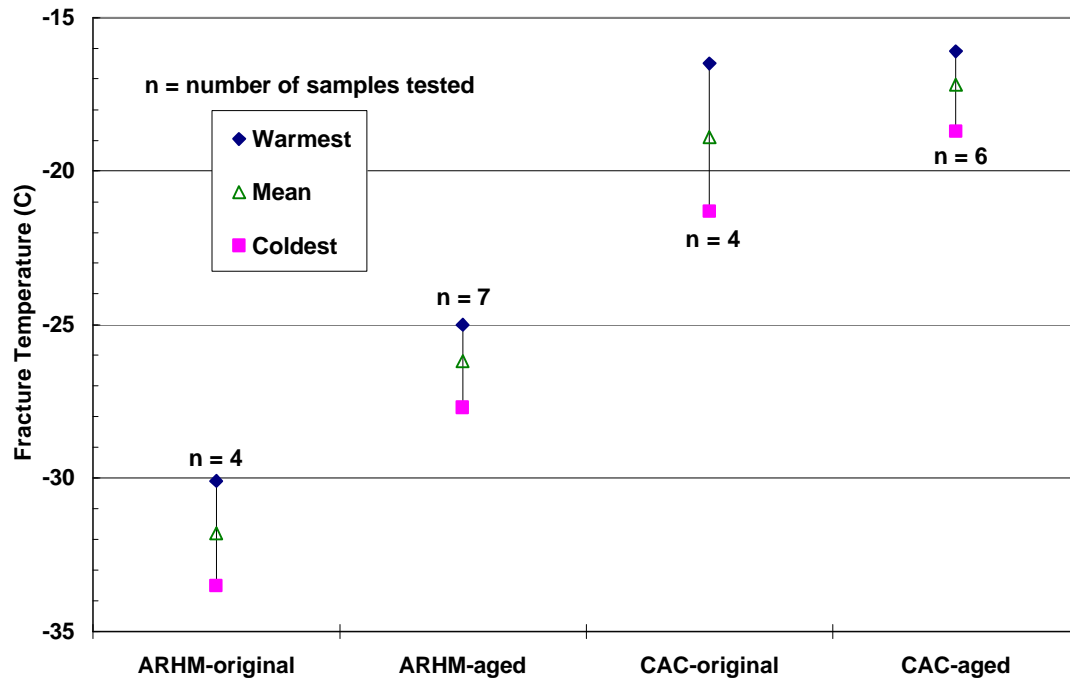

Figure 3. Fracture Temperatures from TSRST.

Fracture temperature test results illustrated in Figure 3 show that aging increases fracture temperature for both mixes (i.e. warmer fracture temperatures for aged mixes). In case of ARHM-GG, fracture temperature increases about 18%, from an average of -32°C for the original mix to -26°C for the aged mix. A smaller increase is seen for CAC-DG (about 2°C), representing about 9% increase in fracture temperature for the aged mix in comparison with the original mix. Results also show that ARHM-GG has lower fracture temperatures than CAC-DG for both original and aged conditions.
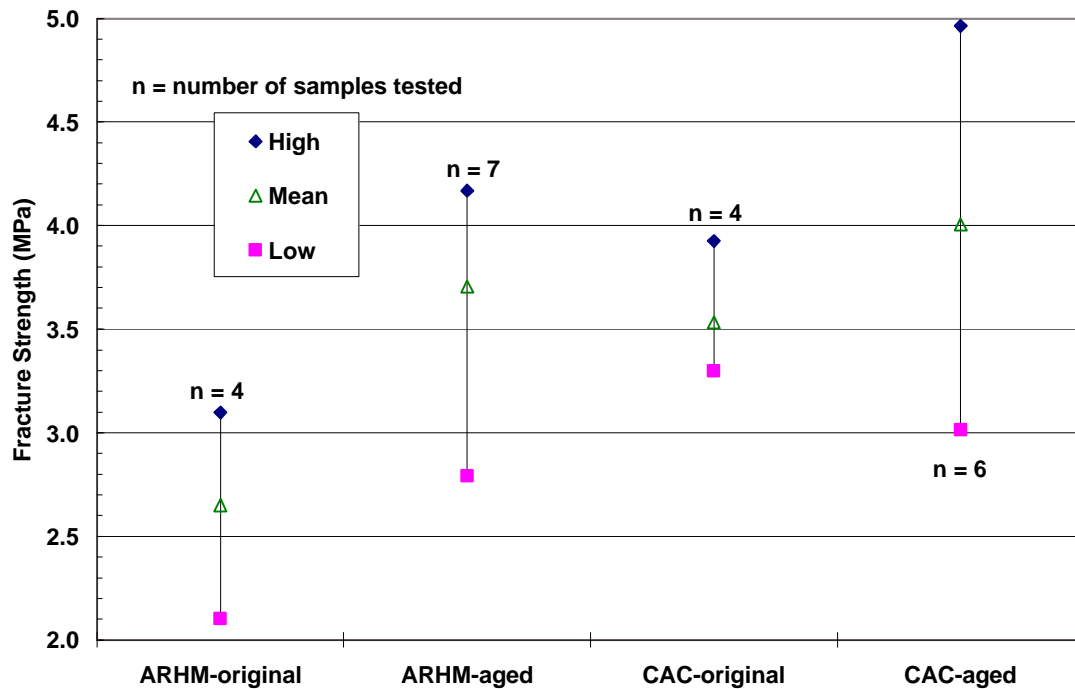
Figure 4. Fracture Strengths from TSRST.

Figure 4 shows that aging increases fracture strengths of ARHM-GG and CAC-DG by 40 % and 13%, respectively. ARHM-GG has smaller fracture strengths than CAC-DG for both original and aged conditions. Although fracture strength increases, usually mix stiffness also increases and the material may become brittle thereby leading to a greater tendency to fracture at low temperatures. This is evidenced by an increase in the fracture temperature values of the aged mixes (i.e. warmer fracture temperatures). Therefore, it is expected that, with aging, mix fracture resistance decreases.

These results indicate that the incorporation of rubber in mixes improves the resistance to thermal cracking over the life of a mix. This is not surprising since it is well known that binder properties and rheological characteristics control the low temperature cracking resistance of a mix.

RUTTING EVALUATION

The Georgia Loaded Wheel Test (GLWT) [12] was used to assess the permanent deformation characteristics of both mixes. The GLWT tests three replicate asphalt concrete slabs at a time. Each slab is 3" deep, 5" wide and 12" long. The slabs are conditioned for 24 hrs at 40°C (105°F) then tested in a 40°C environment. The three slabs are placed on a reciprocating table which moves back and forth at 45 cycles a minute. A 690-kPa pressurized stiff rubber hose is positioned across the top of each slab and a

loaded steel wheel applies a vertical load of 445 N on top of each hose. The test is run for a predetermined number of cycles to create a rut. One cycle is two passes of the wheel. Measured rut depths are averaged for the three replicate slabs. For this study, deformations were measured at 1000, 4000 and 8000 cycles. Figure 5 shows the rut accumulation with cycles for both mixes.
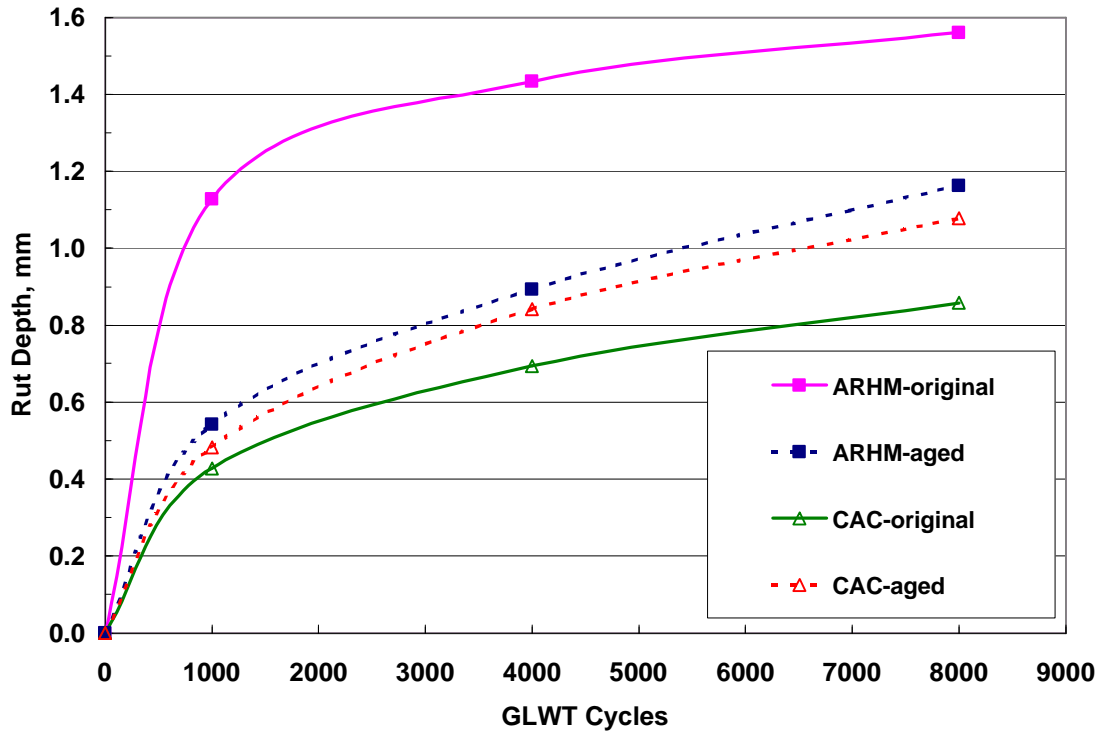

Figure 5. Georgia Loaded Wheel Test Results.

Results show that CAC-DG outperforms ARHM-GG in resisting permanent deformation for both original and aged conditions. At 8000 cycles, the original ARHM-GG exhibits almost double the deformation observed for original CAC-DG. After aging, ARHM-GG deforms about 7% more than CAC-DG.

Figure 5 also shows that the effects of aging are not similar for ARHM-GG and CAC-DG. While aging seems to decrease the rutting potential of ARHM-GG, an increase in rutting is observed for CAC-DG after aging. It should be mentioned that all mixes tested had similar air voids content (Tables 1 and 2).

The rate of rut accumulation is an important factor to assess the permanent deformation characteristic of a mix. Figure 6 illustrates the rut accumulation with logarithmic cycles, and presents linear regressions relating rut depth to log cycles. The slope of a regression line (the coefficient of x) is a measure of the rate of rut accumulation for a mix. An examination of slope values shown in Figure 6 reveals that

aging accelerates rut accumulation for both ARHM-GG and CAC-DG. It is interesting to note that this increase in slope value, from original to aged, is about 39% for both mixes.
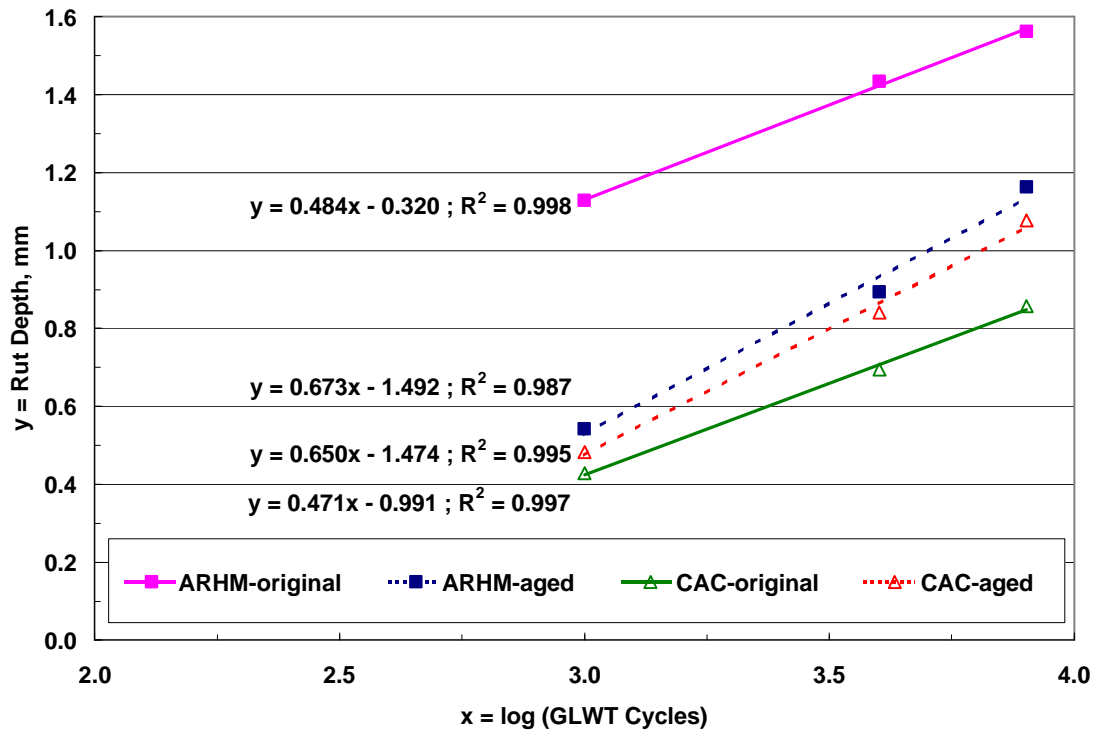

Figure 6. Rates of Rut Accumulation in the GWLT.

SUMMARY AND CONCLUSIONS

A study was undertaken to investigate the influence of field aging on the fatigue, rutting and thermal cracking performance of asphalt concrete and asphalt-rubber concrete. Two California mixes were investigated: conventional asphalt concrete dense graded (CAC-DG) and asphalt-rubber hot-mix gap graded (ARHM-GG). Test results for the aged mixes were compared with data for the original (unaged) materials.

Laboratory fatigue tests were conducted on beam specimens using controlled-strain flexure tests at 22°C and –2°C. Results indicate that field aging reduced the beam fatigue life of CAC-DG. This reduction was more significant for tests run at –2°C than at 22°C. In case of ARHM-GG, aging had negligible effect on fatigue life for tests conducted at 22°C. At –2°C, the reduction in fatigue life for ARHM-GG became more evident, but remained less significant than that for CAC-DG.

It should be mentioned that the influence of aging on pavement fatigue life depends not only on the stiffness of the mix and its fatigue properties but also on the stiffness or layer moduli of the pavement components. Therefore, to assess the influence of field aging on the fatigue performance of runway asphalt pavements, multilayer elastic (or finite element) analysis should be performed on typical runway pavement sections, where mix stiffnesses and fatigue relationships developed in this study are used. Although tensile strain in the pavement surface layer is considered in general as the critical response parameter for fatigue behavior, the use of distortion energy may be more appropriate for conditions of small tensile strains values or when the strain is compressive.

Thermal stress restrained specimen tests were performed to determine the fracture temperature and the corresponding fracture strength of mixes. Results showed that field aging increases fracture temperature and fracture strength for both mixes. However results indicate that ARHM-GG, consistently, has lower (colder) cracking temperature and smaller fracture strength than CAC-DG.

Permanent deformation evaluation of mixes used the Georgia Loaded Wheel Tester at 40°C. Results showed that CAC-DG deformed less than ARHM-GG for both original and aged conditions. However both aged mixes exhibited the same rate of rut accumulation with cycles.

In general, it can be concluded that the effects of aging on asphalt rubber hot mix properties are less significant than that of the conventional mix. The above findings are significant in the selection process for surface course materials for runways.

DISCLAIMER

The contents of this paper reflect the views of the authors, who are responsible for the accuracy of the data presented. The contents of this paper do not necessarily reflect the views or policies of the University of Alaska, the Alaska Department of Transportation and Public Facilities or any local sponsor. This work does not constitute a standard, specification, or regulation.

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